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# Groundwater Modeling Work Plan
# Sites 1 and 3 and the Eastern Plume
# Naval Air Station, Brunswick, Maine

U.S. NAVAL AIR STATION
BRUNSWICK, MAINE

*Prepared for*

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50 D'Angelo Drive
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January 2006
Revision: FINAL
61771.04

959

EA Engineering, P.C.
EA Science and Technology

# LETTER OF TRANSMITTAL

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**TO**
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Lester, Pennsylvania 19113-2090

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| DATE: 1/30/06 | JOB NO.: 61771.04 |
| ATTENTION: Mr. Lonnie Monaco | |
| RE: Groundwater Modeling Work Plan | |

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**SIGNED** Gina M. Calderone
Gina M. Calderone, P.G., CPG
Project Manager



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# Groundwater Modeling Work Plan
# Sites 1 and 3 and the Eastern Plume
# Naval Air Station, Brunswick, Maine

U.S. NAVAL AIR STATION
BRUNSWICK, MAINE

Prepared for

ECC
50 D'Angelo Drive
Marlborough, Massachusetts 01752


Gina M. Calderone, P.G., CPG — 30 January 2006
Project Manager — Date

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Project Geologist — Date


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# 1. INTRODUCTION

EA Science and Technology has been tasked by Environmental Chemical Corporation to develop a groundwater flow model for Sites 1 and 3 and the Eastern Plume at Naval Air Station, Brunswick, Maine. The groundwater flow model will support the Navy with ongoing groundwater treatment system operations and improvements. A site location map is shown on Figure 1. The primary features of the site are shown on Figure 2.

This Groundwater Modeling Work Plan has been prepared to summarize the general approach that will be followed during model development and to document the process by which the modeling efforts will be completed.

Responses to comments received from site regulators on the draft version of this Work Plan are provided in Appendix A.

A 3-dimensional modeling effort was previously completed for the site by ABB Environmental Services, Inc. for the U.S. Navy (ABB-ES 1993). The previous modeling work, summarized in the ABB report entitled *Numerical Modeling Report*, provides an overview of site conditions and will be used as a starting point for the modeling process. The new model will expand upon the previous model and assist site decision-makers with assessing remedial options for Sites 1 and 3 and the Eastern Plume.

## 1.1 MODELING OBJECTIVES

As part of this effort, EA is developing a groundwater flow model that will be used to achieve the two primary objectives shown below:

1. Develop a reliable simulation of groundwater flow which can define the capture effectiveness of the extraction well network in the Eastern Plume.

2. Assess the effects of the cap and slurry wall at Sites 1 and 3 on downgradient areas such as Mere Brook.

This Work Plan describes the process by which the model will be developed so that these objectives can be achieved.

## 1.2 MODEL CODES

Pre- and post-processing will be completed using the Groundwater Modeling System (GMS) Program, Version 5.0. The groundwater flow model will be developed using MODFLOW 2000 (Harbaugh et al. 2000) computer code. MODFLOW is run directly through the GMS package. MODFLOW has been heavily tested and is the industry standard for groundwater flow software. The MODFLOW model is run directly through the GMS pre-processor, and output results can be viewed in graphical or tabular form. Particle tracking will be completed using MODPATH. This software is supported by GMS and relies upon data from the MODFLOW results to compute path lines and groundwater flow velocities.

# 2. SITE CONDITIONS

A brief overview of site conditions is presented in this section to provide a summary of the major features that will be included in the groundwater model. Extensive amounts of additional information are available in the Remedial Investigation (E.C. Jordan 1990), Supplemental Remedial Investigation (E.C. Jordan 1991), and the previous Groundwater Modeling report (ABB-ES 1993). The current understanding of site geology has also been greatly expanded since the previous model was completed with data collected from investigations in the Southern Boundary area, as summarized in the Summary Report for the Direct-Push Investigation at the Southern Boundary of the Eastern Plume (EA 2004), as well as other investigations. A general overview of the site geology has been developed in conjunction with site decision makers in the Conceptual Model for the Eastern Plume (EA 2003). Available site data will be utilized to develop an accurate groundwater flow model which is reflective of known site conditions.

## 2.1 SITE GEOLOGY AND HYDROGEOLOGY

The stratigraphy of the portion of Naval Air Station Brunswick that includes Sites 1 and 3 and the Eastern Plume is comprised of interbedded sand, silt, and clay units that overlie the undulating bedrock surface and some occasional discontinuous till, with the exception of the upper sand and till. The majority of the overburden units at the Eastern Plume are interpreted to be part of the Presumpscot Formation. This Formation is comprised of water-laid clay, silt, and sand with some minor gravel units (E.C. Jordan 1990). The formation exhibits a general coarsening upwards sequence (E.C. Jordan 1990). Three major overburden layers are present: upper sand, transition which contains a sandy interval often referred to as the lower sand, and clay.

The Presumpscot Formation was deposited on the ocean floor during a submergence of the area during the last period of glaciation. Sediments were deposited over a till or directly over bedrock (E.C. Jordan 1990). The Presumpscot clay and transition are comprised of marine deposits (i.e., deposited under low energy marine conditions) which resulted in the generally fine-grained nature of the overburden material. Clay thickness is variable but generally ranges from less than 10-ft thick to more than 80-ft thick (E.C. Jordan 1990).

The upper sand unit has a non-marine origin, and was deposited by the Androscoggin River as it shifted laterally in a post-glacial course following a drop in sea level. In some areas, the upper sand was reworked by wind action. Following deposition of these units, streams have carved steep sided gullies into these units, particularly the upper sand (E.C. Jordan 1990).

The site conceptual model (EA 2003) contains the following descriptions of the significant water-bearing units at the site:

- The upper sand unit consists of a fine sand that readily transmits groundwater. The unit is approximately 10- to 20-ft thick across the Eastern Plume area. In the vicinity of Sites 1 and 3, the upper sand unit thickens to greater than 40 ft (EA 2000). The upper layers of fine sand are mostly silt-free and have the highest conductivity of the overburden units (E.C. Jordan 1990).

- The transition unit lies between the upper sand and the clay, and is composed of interbedded sand, silt, and clay (E.C. Jordan 1990). The transition unit ranges in thickness from 0 to 80 ft (EA 2000). The transition forms a wedge that increases in thickness from west to east across the Eastern Plume, and pinches out just east of the Eastern Plume. The upper portions of the transition unit exhibit unconfined groundwater conditions, while deeper intervals in the transition exhibit confined conditions due to the presence of low permeability zones within this unit. The majority of the transition unit is silt and clay, although sand layers are present with thickness ranging from inches to several feet. The transition unit contains relatively thin and possibly continuous sand layers that may act as preferential pathways for groundwater movement within this unit. A mappable sandy interval has been identified near the base of the transition unit in some portions of the Eastern Plume. This sandy interval is referred to as the lower sand. Both the upper and lower sands have been targeted by remedial extraction at the Eastern Plume since remedial operations (i.e., groundwater pump and treat) were started in 1995. Approximately 430 kg of contaminant mass has been removed by the extraction system and destroyed by the treatment plant as of the end of 2003—the bulk of the mass resided in the deep sand unit.

- Vertical movement of groundwater is limited by fine-grained interbeds of the transition, and vertical hydraulic conductivity is at least one order of magnitude lower than horizontal hydraulic conductivity (E.C. Jordan 1990). The transition unit is acting as an aquitard between the shallow sand and lower sand. The lateral continuity of transition zone sand layers appears highly variable, and some sand layers may provide conduits to groundwater flow, although others may be isolated and may not conduct significant amounts of groundwater (E.C. Jordan 1990).

- The transition unit has a horizontal hydraulic conductivity 1-2 orders of magnitude below that of the upper sand (E.C. Jordan 1990). Hydraulic conductivity for the transition units ranges from $10^{-4}$ to $10^{-5}$ cm/sec (from 0.3 to 0.03 ft/day) for the fine grained interbeds, and can range up to $10^{-3}$ cm/sec (3 ft/day) for sandy intervals (E.C. Jordan 1990). Although not tested, the vertical hydraulic conductivity is believed to be one order of magnitude lower than the horizontal hydraulic conductivity.

- The Presumpscot clay underlies the transition unit and is draped over the bedrock or till surface in a nearly continuous layer. The clay has low permeability which ranges from $10^{-6}$ to $10^{-8}$ cm/sec (from $3 \times 10^{-3}$ ft/day to $3 \times 10^{-5}$ ft/day) (E.C. Jordan 1990). The clay thickness has been measured up to 80 ft, although the thickness of the clay may be greater in some areas (EA 2000). In one area, near MW-323, the clay appears to be very thin or may not be present. The remaining portions of the Eastern Plume appear to be underlain by several feet or tens of feet of clay. This clay forms the base of the overburden flow system and prevents significant groundwater flow between the overburden and bedrock or till.

- A geophysical investigation was completed by the U.S. Environmental Protection Agency in late 2003 for Site 11 and areas to the east (Hager Geoscience 2004). The results of the geophysical investigation focused on identifying unit thickness and the top elevations of the transition, clay unit, and bedrock. The topography of the top of the clay unit is similar to the top of bedrock surface, exhibiting an easterly slope from high elevations near Site 11, decreasing eastward. However, the thickness of the clay also shows considerable variation over the entire plume. Minimal clay thickness was noted east of Site 11 (0- to 10-ft thick) with much greater thickness (up to 110+ ft) noted further east in the vicinity of a bedrock depression parallel with the Weapons Area Road. The clay thins further east toward Picnic Pond with a thickness varying from near 0 to 25 ft. The top elevation and thickness of the transition unit generally mimics the clay, showing an eastward slope with greatest thickness noted where bedrock depressions are present.

## 2.2 EXISTING PUMP-AND-TREAT SYSTEM

Groundwater extraction has been occurring via a network of extraction wells since 1995 to reduce volatile organic compound concentrations and maintain hydraulic control of the Eastern Plume. Deep overburden groundwater flow patterns have been locally altered by pumping at extraction wells, but only small changes in groundwater flow patterns have been measured away from the immediate vicinity of most extraction wells. The largest changes in lower groundwater flow patterns are seen at EW-2A, which was installed to intersect only the lower sand interval. Potentiometric head at this location has been approximately 12 ft lower than noted in the shallow flow system (EA 2000). Extraction well EW-5 has been replaced by EW-5A, which is screened only across the deep sand interval. Other operating extraction wells (EW-1 and EW-4) are screened across the upper sand and lower transition intervals. Effects on the deep flow system due to extraction well pumping at these two wells have been limited due to shallow groundwater preferentially moving into extraction wells. Overall, the groundwater extraction system has not established hydraulic control of the Eastern Plume, although natural geologic conditions appear to have helped contain movement of groundwater contamination.

## 2.3 GAUGING DATA

Numerous rounds of groundwater gauging data and contaminant concentration data are available for site monitoring wells. Site monitoring wells have been gauged and sampled on a quarterly or semi-annual basis from 1995 to present. A site-wide database of gauging data and laboratory analysis is maintained for the site and will be used during the project for model calibration and validation. Data from sampling points included in the Long-Term Monitoring Program for Sites 1 and 3 and Eastern Plume will be used during model development.

# 3. MODEL DEVELOPMENT

The groundwater flow model will be developed as a simplified version of the natural flow system. The model will be based upon known site conditions whenever possible, and will also rely upon other data, i.e., precipitation measurements or literature values, if no site-specific data are available. The primary input values for the groundwater flow model include geological data such as hydraulic conductivity, porosity, specific yield, and specific storage, and more general data such as precipitation, stream elevations, and stream conductance. In addition, other site conditions will be included such as extraction well flow rates and operation of the infiltration gallery. These data will be input into the flow model and the model generated water elevations will be compared to actual data to determine the accuracy of the flow model. The model input values will be adjusted within reasonable ranges until the results of the model are considered to be sufficiently accurate for use as a predictive tool.

The following sections provide descriptions of the specific data that will be used during model development.

## 3.1 UPPER SAND

The upper sand unit consists of a fine sand that readily transmits groundwater. The unit is approximately 10- to 20-ft thick across the Eastern Plume area. In the vicinity of Sites 1 and 3, this upper sand unit thickens to greater than 40 ft (EA 2000). The upper layers of fine sand are mostly silt-free and have the highest conductivity of the overburden units (E.C. Jordan 1990). This unit is unconfined and receives recharge via precipitation directly from the ground surface. The groundwater flow direction in this unit is well established, with groundwater moving toward stream channels (i.e., Mere Brook and associated tributaries). Hydraulic conductivity for this unit ranges from 0.009 to 49.05 ft/day with a geometric mean of 4.59 ft/day (E.C. Jordan 1990 1991) as measured by slug testing (data provided in Table 1). The existing groundwater extraction well network has created localized areas of drawdown which disrupt the overall groundwater flow pattern in a localized area near extraction wells. Surface waterbodies are known to affect groundwater flow patterns of the shallow sand. Potentiometric head values in this unit are well documented as noted in water level data from numerous monitoring wells and extraction wells.

Flow simulations will focus on recreating conditions in the Upper Sand in addition to the other stratigraphic units present at the site. The aquifer parameters specified in the previous groundwater modeling effort will provide a starting point for these modeling efforts. In addition, site-specific aquifer parameters such as slug test results will be used during model development.

The Upper Sand will be modeled as two layers to account for changing thickness across the model domain. The thickness of Upper Sand model layers will be input from existing boring logs and is known to vary significantly due to changes in ground surface elevation and the top of the transition unit.

## 3.2 TRANSITION UNIT

The transition unit lies between the upper sand and the clay, and is composed of interbedded sand, silt, and clay (E.C. Jordan 1990). The transition unit ranges in thickness from 0 to 80 ft (EA 2000). The transition forms a wedge that increases in thickness from west to east across the Eastern Plume, and pinches out to the east of the Eastern Plume. The upper portions of the transition unit exhibit unconfined groundwater conditions, while deeper intervals in the transition exhibit confined conditions due to the presence of low permeability zones within this unit. The majority of the transition unit is silt and clay, although sand layers are present with thickness ranging from inches to several feet. Measured hydraulic conductivity for this unit ranges from 0.0001 to 36.85 ft/day with a geometric mean of 0.52 ft/day (E.C. Jordan 1990, 1991) (data provided in Table 2). The transition unit contains relatively thin and possibly continuous sand layers that may act as preferential pathways for groundwater movement within this unit, which will be modeled separately as the lower sand unit.

The transition will be modeled as four layers to account for changes in unit thickness over the model domain. Two of those layers will represent the lower sand sub-unit. The thickness of transition model layers will be input from site boring logs.

### 3.2.1 Lower Sand Sub-Unit Model Layers

A laterally continuous sandy interval has been identified near the base of the transition unit in many portions of the Eastern Plume. This sandy interval is referred to as the lower sand. There are no hydraulic conductivity measurements (i.e., slug test data) directly from this stratigraphic unit although the unit has been well described in numerous boring logs. It is anticipated that selected wells screened within the lower sand sub-unit will be slug tested to evaluate the range of conductivities for this unit.

The lower sand sub-unit will be modeled as two layers to account for changes in unit thickness over the model domain. Greater vertical discretization using additional model layers may be required once the modeling effort is underway. The thickness of the lower sand model layers will vary depending on the top and bottom elevations of the lower sand unit as recorded in site boring logs.

## 3.3 BOUNDARY CONDITIONS AND MODEL DOMAIN

The area included in the groundwater flow model is referred to as the model domain. This area will be bounded by the edges of the model grid and active cells within this area will be included in the flow model. Naturally occurring hydrogeologic boundaries will be used to define the horizontal and vertical extents of the model domain.

Drainage divides identified by State of Maine Geographic Information System layers will be used to define the majority of the model boundary conditions. The model domain will be extended to these divides toward the north, west, and east of the site. Drainage divides will be modeled as no-flow boundary conditions. A constant head boundary condition will be used along the west of the domain (near the runways) and along the southeastern boundary. A river boundary condition will be used along a tributary of Mere Brook on the southern edge of the model domain. Figure 3 presents the anticipated configuration of the model domain. Note that some variation from this conceptual model design will likely be required during model development depending on the results of initial model simulations.

The very low conductivity of the Presumpscot clay acts to effectively limit groundwater flow downward into this unit. Therefore, the top of clay surface will form the base of the model domain. Bedrock will not be included in the groundwater flow model as insufficient data are available to accurately simulate bedrock conditions and bedrock is not affected by the groundwater extraction network in the Eastern Plume or the landfill at Sites 1 and 3.

It is anticipated that a uniform recharge rate will be applied across the model domain. However, subsequent zonation may follow, depending upon the results of the initial calibration runs. Paved areas within the model domain will be taken into account when specifying different recharge zones.

The size of the model grid nodes will be established based on the spacing of monitoring wells. The model grid will be spaced so that one model grid block will contain one monitoring well for each interval so unique elevation data can be obtained at each monitoring well. It is anticipated that the model grid will be composed of cells that range in size from a maximum size of 200 ft on a side to a minimum size of 10 ft on a side. The grid will have the highest resolution in areas with the majority of monitoring wells which corresponds to the areas of the Eastern Plume and Sites 1 and 3. Away from these areas, the size of the grid nodes will increase toward the outside of the model domain. The actual size and spacing of the model grid will be determined during model development.

## 3.4 GROUNDWATER EXTRACTION AND INFILTRATION SYSTEM

A network of groundwater extraction wells is present at the Eastern Plume and Sites 1 and 3. At the Eastern Plume, a total of 7 extraction wells have been in operation at some time since 1995. These wells are EW-1, EW-2, EW-2A, EW-3, EW-4, EW-5, and EW-5A. Flow rates from these wells have varied since groundwater extraction was initiated in 1995. Flow data have been measured on a periodic basis and monthly flow data will be used during model development. At Sites 1 and 3, 2 extraction wells (EW-6 and EW-7) were in operation between 1995 and 1997. These wells were deactivated after water elevations stabilized within the landfill slurry wall. Between 1995 and 2003, the groundwater extracted from the aquifer was treated and removed from the site via sewer district disposal. An infiltration gallery was constructed to facilitate groundwater recharge directly to the aquifer. The infiltration gallery and monthly discharge rates will be included during the development of the groundwater flow model.

# 4. MODEL CALIBRATION

Calibration is the process of refining the model input parameters so that the desired degree of correspondence is observed between the model simulations and actual data from the site. For a groundwater flow model, calibration involves adjusting model parameters, such as recharge, hydraulic conductivity, boundary conditions, and other model input values. During calibration, model input parameters are varied over realistic ranges taken from site data or, when necessary, literature values. To avoid unnecessary model complexity, calibration will initially assume model layers are homogeneous for each aquifer parameter, including hydraulic conductivity, recharge, and other input parameters. If necessary, during calibration, parameter values will be changed within a portion of a model layer to improve model results.

Flow model calibration will be completed in accordance with the American Society for Testing and Materials Standard Guide for Calibrating a Groundwater Flow Model Application, D5981-96. Calibration will be completed following these guidelines:

- **Model Input Parameters**—The model will use data from the previous model and data gathered since then as a starting point for model calibration. The initial model input parameters are summarized in Table 3. These parameters will be the primary focus of model calibration.

- **Calibration Techniques**—Calibration will initially be completed for the flow model by manual manipulation. After an initial phase of manual calibration, automated parameter estimation may be used to fine-tune the model calibration using the Parameter Estimation Software that is part of the GMS program. Automated calibration uses a computer code to adjust model inputs so that minimum values for residual values are achieved.

- **Flow Model Calibration**—The primary data available at the site for flow model calibration are water elevation measurements. Flow model calibration will be completed for steady-state conditions when extraction wells are affecting the flow field. Water elevation data that will be used for calibration include data sets collected between 1995 and present. In addition, depending on the results of the steady-state flow model, a transient calibration simulation may be completed. Transient conditions will be simulated by varying extraction well pumping rates at individual extraction wells and comparing modeled results to measured data at nearby monitoring wells. For transient simulations, water drawdown will be used as calibration goals rather than measured water elevations. As per the previous modeling effort, observed heads at wells near extraction wells will be compared to modeled heads. These head values will be tracked over time to assess the predictive capacity of the model under transient conditions. Monitoring wells to be included during transient simulations will be selected during the calibration process following data review.

Transient calibration will include the following:

— The site database contains pumping rate data for extraction wells from 1995 to present. Extraction well pumping rates will be input into the model to simulate past pumping conditions. Similarly, flow rates into the infiltration gallery will be input into the model based on data from the groundwater extraction system.

— Modeled groundwater elevations will be compared to measured elevations for monitoring wells located throughout the plume. Approximately 10 monitoring wells will be selected for time versus drawdown comparisons for the 1995-2002 period. Selected monitoring wells will be located across Sites 1 and 3 and the Eastern Plume, and will be used to estimate the accuracy of the overall transient calibration. The wells to be included in the transient calibration will be determined during model calibration.

— Transient calibration results will be summarized in graphical and tabular form to document the modeled versus measured water elevations between 1995 and present.

Transient model time steps will be based on the interval for which extraction well data were recorded. Quarterly extraction well flow readings were recorded in most cases. Therefore, model time steps will be quarterly (i.e., every 3 months) between 1995 and present.

- **Calibration Targets**—Monitoring well head data will be used as calibration targets for the flow model simulation. The flow model will be of moderate to high fidelity (i.e., will be designed to strongly resemble the natural hydrogeologic system). Calibration targets will include monitoring wells included in gauging rounds completed from 1995 to present.

  The acceptable error for water elevation residual values will be based on the average fluctuation of water elevations for monitoring wells located at the site. Water elevations were reviewed for monitoring wells between 1995 and 2004, as summarized in Table 4. To assess the amount of variability for each well, the standard deviation was calculated. The average variability noted in site water elevations is 1.73 ft (Table 4). The standard deviation represents the amount of natural variation in water elevations across the model domain since gauging data have been collected. Therefore, the standard deviation of 1.73 ft will be used as a calibration target for the model under steady-state and transient conditions. If possible, the residual errors of the flow model will be minimized to below the calibration goal so the model represents actual conditions as closely as possible.

## 4.1 MODEL VERIFICATION

Model verification is the process by which the calibrated model is compared to an independent data set that was not used for model calibration. This establishes greater confidence that the calibrated model can reproduce site conditions. The calibrated flow model will be compared to the most recently available gauging data (September 2005), and the accuracy of the comparison will be presented in the Modeling Summary Report.

## 4.2 SENSITIVITY ANALYSIS

A sensitivity analysis will be completed to qualitatively assess how changes in model input affect model output results. The primary goal of the sensitivity analysis will be to identify which parameters are the least well defined and most critical to the model.

A general sensitivity analysis will be completed early in the flow modeling process to establish which aquifer parameters have the largest effect on groundwater flow results. Parameters that will be changed as part of the sensitivity analysis will include hydraulic conductivity, vertical conductivity, and recharge.

A second, more detailed sensitivity analysis will be completed following model calibration. This will include completing a sensitivity analysis of the flow model. At a minimum, parameters will include the following: hydraulic conductivity, vertical conductivity, and recharge. The vertical discretization of the various stratigraphic layers will also be adjusted during sensitivity analysis. Results will be summarized in tabular form, showing the net effect of parameter change and the relative effect on model results.

## 4.3 REPORTING

A summary report will be generated to document the modeling process and output results. The summary report will include written and graphical presentations of model assumptions and objectives; the conceptual model; model code description; model development; and calibration, validation, and sensitivity analysis. The summary report will be developed as noted in American Society for Testing and Materials Guidance D5718-95, *Standard Guide for Documenting a Groundwater Flow Model Application.*

The summary report will be submitted to site stakeholders for review and comment. A response to comment letter will be developed and, following regulator concurrence, a final report will be issued. After the model calibration is finalized, the model will be used to complete predictive scenarios as described in Section 5.

# 5. PREDICTIVE SCENARIOS

The calibrated flow model will be used to complete several predictive scenarios in support of ongoing remedial measures for Sites 1 and 3 and the Eastern Plume. The overall effectiveness of the remedial measures has not been previously assessed quantitatively, and the calibrated model will be used for this purpose. The two primary objectives of the modeling effort are shown below along with the anticipated methods which will be used to address each objective. The results and findings of these assessments will be documented in a separate letter report scheduled to be issued after the Final Model Summary Report is issued.

- **Objective 1 – Develop a Reliable Simulation of Groundwater Flow which can Clearly Define the Capture Effectiveness of the Extraction Well Network in the Eastern Plume**—This goal will be achieved by using the calibrated flow model to evaluate the effectiveness of the existing remedial system using a systematic approach drawing from multiple lines of evidence. The six-step process has been outlined by the U.S. Environmental Protection Agency Region 10 (Greenwald et al. 2005) and is based on a forthcoming guidance document. The six specific goals used to complete this assessment include the following:

  1. Step 1 – Review site data, site conceptual model, and remedy objectives
  2. Step 2 – Define site-specific target capture zones
  3. Step 3 – Interpret water levels using potentiometric surface maps
  4. Step 4 – Perform particle tracking using groundwater flow model
  5. Step 5 – Evaluate concentration trends
  6. Step 6 – Interpret actual capture zones based on Steps 1 through 5, compare to target capture zones, and assess uncertainties and data gaps.

  This process allows site decision-makers to more fully visualize and understand the effective capture zone of the extraction well network. These results can be used by site decision-makers during the planning of additional extraction wells or during the overall assessment of the effectiveness of the extraction network.

- **Objective 2 – Assess the Effects of the Cap and Slurry Wall at Sites 1 and 3 on Downgradient Areas such as Mere Brook**—This goal will be achieved by using the calibrated flow model to assess how groundwater flow patterns may be affected by the Sites 1 and 3 landfill cap and slurry wall. The MODPATH particle tracking code will be used to illustrate the 3-dimensional groundwater movement directions in plan view and cross-sectional view to assess where impacted groundwater is likely to migrate. The model-generated groundwater flow patterns within and near the Sites 1 and 3 landfill will be used to determine the potential interaction of surface water and groundwater, and to estimate how long impacted groundwater may impact the surrounding areas of Sites 1 and 3.

# 6. MODEL LIMITATIONS

As with all groundwater flow models, the groundwater flow model that will be developed is a simplified representation of a natural system and, therefore, results should be used with a degree of caution. Input parameters used in the flow model will contain uncertainty due to the complexity of a natural system. These uncertainties can become compounded during the estimation of multiple input parameters, resulting in differences between model output and the natural system. Deviations between observed and calculated heads will be present. Several general causes can contribute to non-agreement between model and observed data, including:

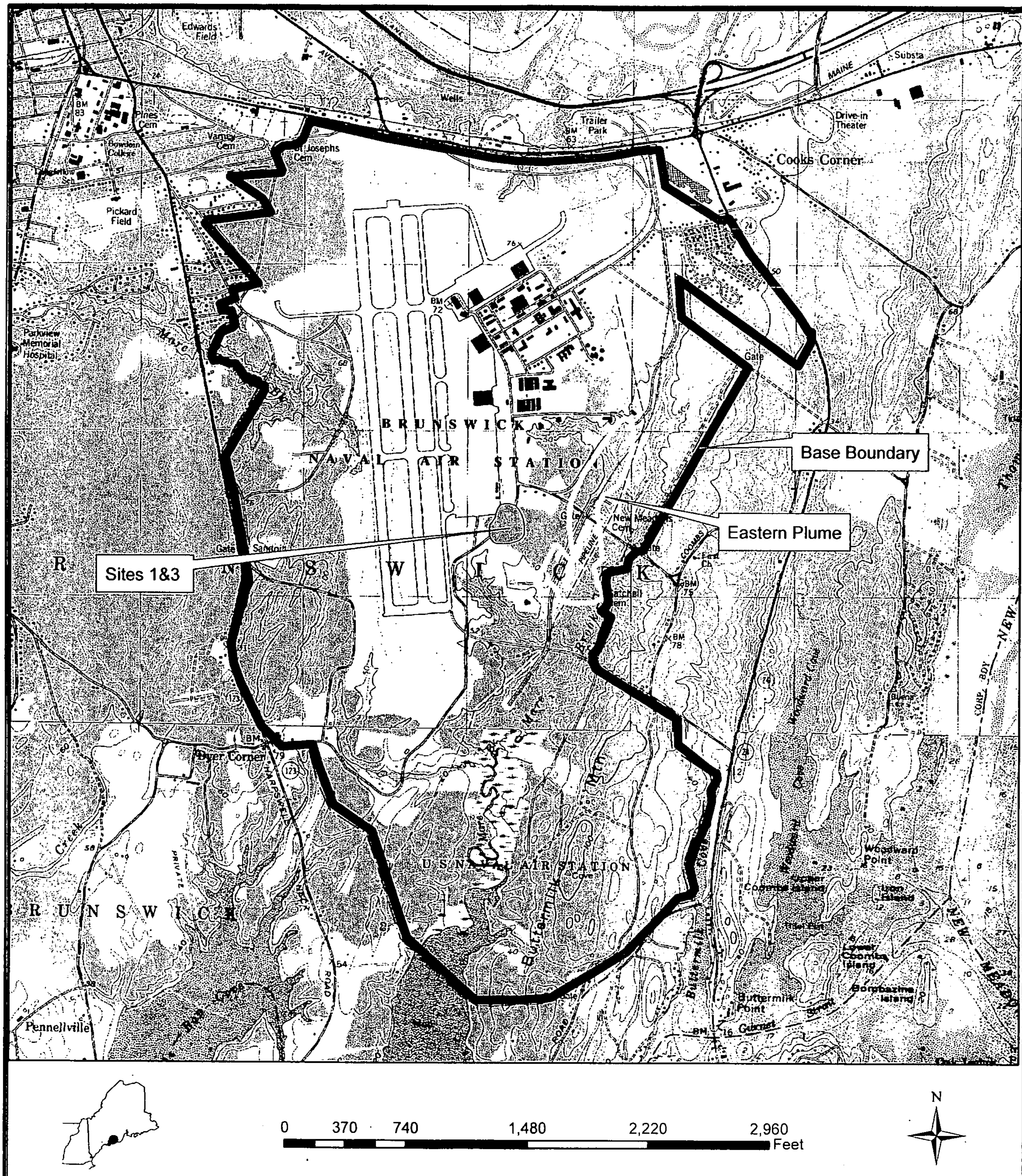
- **Simplifying Model Assumptions**—The natural flow system will be greatly simplified to be modeled. Numerous assumptions will be required to simplify the natural system, or because sufficient site-specific data are not available.

- **Uncertainty in Source and Sink Terms**—In the flow model, water entering the aquifer via source and sink terms (i.e., constant head boundaries or extraction wells) will be assumed to be occurring at a constant rate. However, the natural system is likely to behave differently under periods of high or low precipitation. The model simulations used for this project cannot fully account for the variable conditions that will occur in the natural system.

- **Non-Uniqueness**—One of the most important limitations of the groundwater flow model relates to the issue of non-uniqueness of the solution. Because the model calibration is based on matching head values, changes to several input parameters could provide similar results. More than one combination of model parameters can result in similar head values.

- **Uncertainty in Extraction Well Flow Rates, Infiltration Gallery Flow Rates, and Water Level Measurements**—Extraction well pumping rates and infiltration gallery flow rates have been measured periodically throughout the operation of the pump-and-treat system. Generally, water elevations have been measured on a semi-annual basis. Uncertainty regarding the accuracy and completeness of these measurements may affect the calibration of the flow model.

During the modeling process, efforts will be made to control the uncertainty incorporated into the model. Whenever possible, the assumptions used in the model will be documented so that assumptions and decisions can be discussed and presented to the data user. Sources of data will be noted and referenced and assumptions will be justified based on site-specific data whenever possible.

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| EA® | NAVAL AIR STATION<br>BRUNSWICK, MAINE | FIGURE 1<br>LOCATION MAP OF<br>NAVAL AIR STATION BRUNSWICK |

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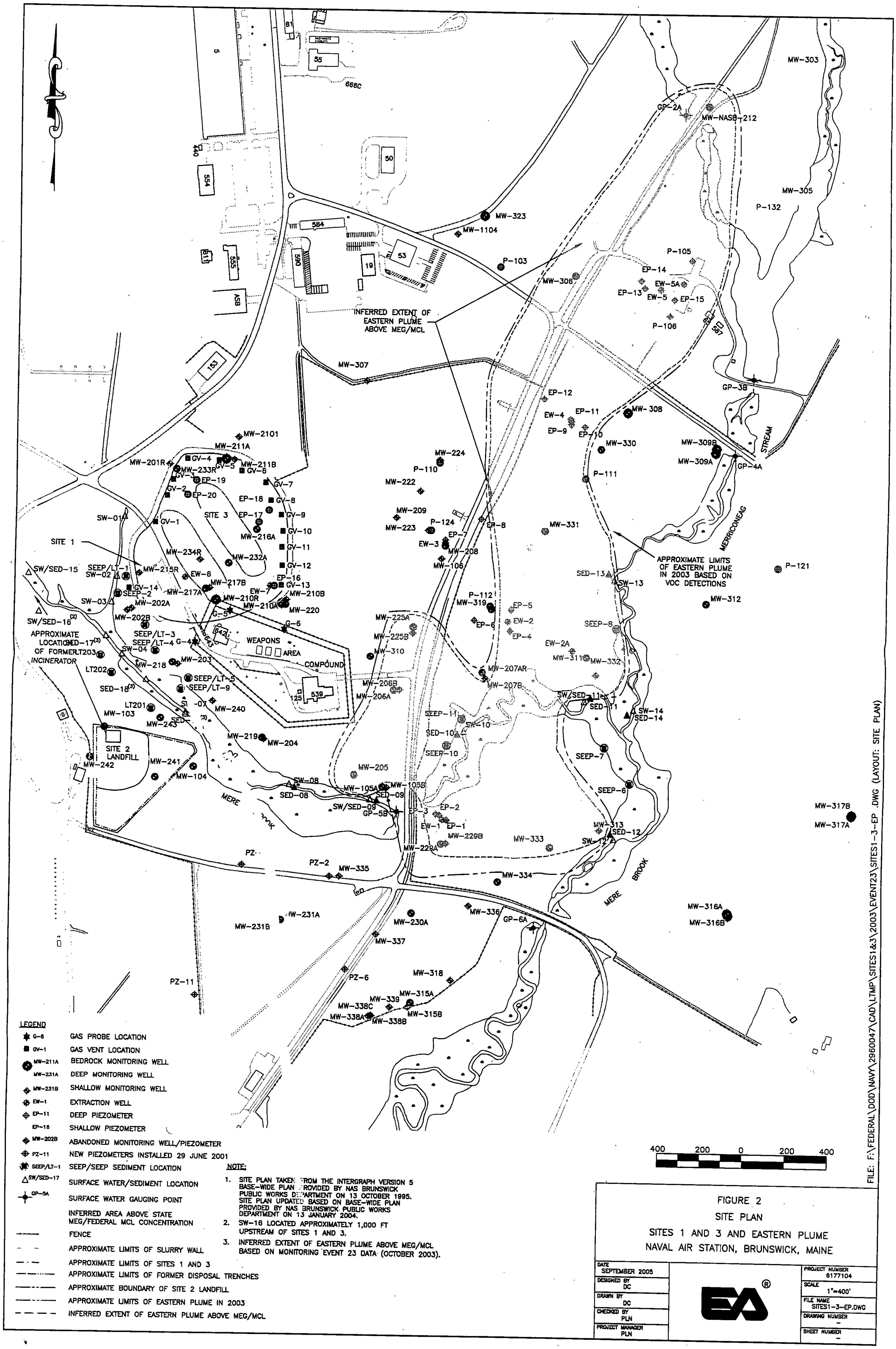
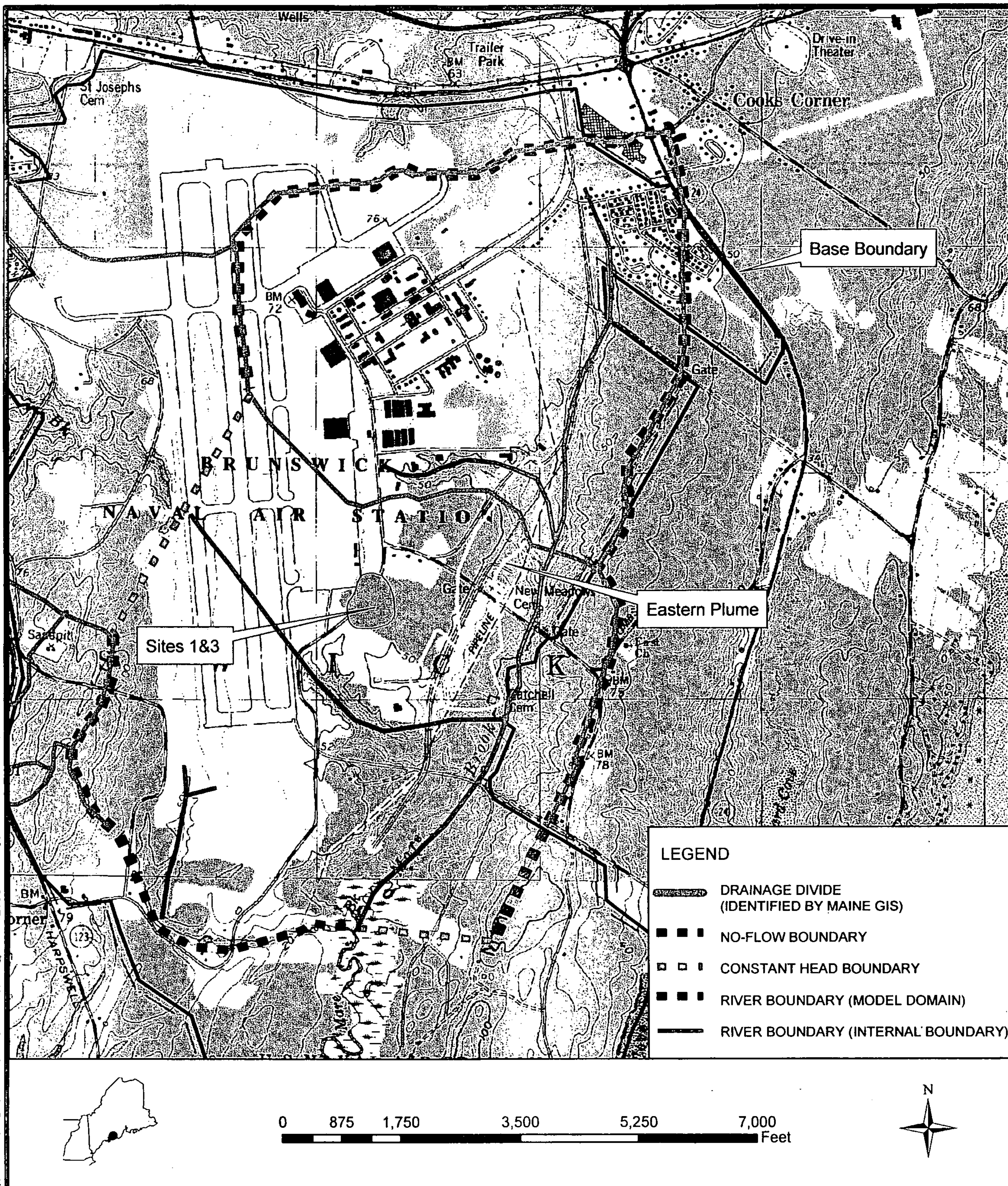



FIGURE 2
SITE PLAN
SITES 1 AND 3 AND EASTERN PLUME
NAVAL AIR STATION, BRUNSWICK, MAINE




| | NAVAL AIR STATION BRUNSWICK, MAINE | FIGURE 3 GROUNDWATER MODEL DOMAIN AND BOUNDARIES |
|---|---|---|

| PROJECT MGR: | DESIGNED BY: | CREATED BY: | CHECKED BY: | SCALE: | DATE: | PROJECT NO: | FILE NO: |
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# TABLE 1 HYDRAULIC CONDUCTIVITY VALUES FOR UPPER SAND

| Well ID | K (ft/day) | Site | Source |
|---|---|---|---|
| MW-104 | 8.22 | 2 | 1 |
| MW-106 | 7.94 | Eastern Plume | 3 |
| MW-1101 | 6.8 | 11 | 1 |
| MW-1102 | 8.22 | 11 | 1 |
| MW-1103 | 3.4 | 11 | 1 |
| MW-1104 | 4.25 | 11 | 1 |
| MW-1301 | 3.12 | Eastern Plume | 1 |
| MW-1302 | 2.27 | Eastern Plume | 1 |
| MW-1303 | 2.38 | Eastern Plume | 1 |
| MW-201 | 49.05 | 1 and 3 | 1 |
| MW-204 | 34.87 | 1 and 3 | 1 |
| MW-205B | 23.53 | Eastern Plume | 3 |
| MW-206A | 4.11 | Eastern Plume | 1 |
| MW-206B | 23.47 | Eastern Plume | 1 |
| MW-207B | 1.36 | Eastern Plume | 1 |
| MW-209 | 25.74 | Eastern Plume | 1 |
| MW-210B | 7.31 | 1 and 3 | 1 |
| MW-211B | 0.61 | 1 and 3 | 1 |
| MW-214 | 2.32 | 1 and 3 | 1 |
| MW-217B | 0.12 | 1 and 3 | 1 |
| MW-219 | 1.56 | 1 and 3 | 1 |
| MW-220 | 1.05 | 1 and 3 | 1 |
| MW-222 | 12.76 | Eastern Plume | 1 |
| MW-223 | 6.8 | Eastern Plume | 1 |
| MW-224 | 10.49 | Eastern Plume | 1 |
| MW-225A | 3.69 | Eastern Plume | 1 |
| MW-225B | 12.76 | Eastern Plume | 1 |
| MW-229B | 0.18 | Eastern Plume | 1 |
| MW-301 | 19.28 | 1 and 3 | 2 |
| MW-302 | 14.46 | 1 and 3 | 2 |
| MW-302 | 16.44 | Eastern Plume | 3 |
| MW-304 | 5.10 | 1 and 3 | 2 |
| MW-306 | 5.67 | 1 and 3 | 2 |
| MW-307 | 28.06 | 1 and 3 | 2 |
| MW-310 | 21.26 | 1 and 3 | 2 |
| MW-314A | 34.02 | Eastern Plume | 3 |
| MW-314B | 8.22 | Eastern Plume | 3 |
| MW-315B | 8.22 | Eastern Plume | 3 |

NOTE: Hydraulic conductivity measurements were used for monitoring wells identified as being fully screened in the sand unit.

Sources:
1. Table 4-3, Remedial Investigation (E.C. Jordan 1990).
2. Table 3-2, Supplemental Remedial Investigation (E.C. Jordan 1991).
3. Table 8-3, Supplemental Remedial Investigation (E.C. Jordan 1991).

| Well ID | K (ft/day) | Site | Source |
|---|---|---|---|
| MW-321 | 31.18 | 1 and 3 | 2 |
| MW-405 | 14.54 | Eastern Plume | 1 |
| MW-406 | 0.71 | Eastern Plume | 1 |
| MW-408 | 5.39 | Eastern Plume | 1 |
| MW-704 | 16.73 | 7 | 1 |
| MW-705 | 17.01 | 7 | 1 |
| MW-706 | 3.01 | 7 | 1 |
| MW-903 | 1.59 | 9 | 1 |
| MW-904 | 1.36 | 9 | 1 |
| MW-905 | 0.009 | 9 | 1 |
| MW-906 | 0.71 | 9 | 1 |
| MW-908 | 1.02 | 9 | 1 |
| OW-813 | 0.85 | 8 | 1 |
| **Geometric Mean** | **4.59** | | |
| **Mean** | **10.25** | | |

# TABLE 2 HYDRAULIC CONDUCTIVITY VALUES FOR TRANSITION

| Well ID | K (ft/day) | Site | Source |
|---|---|---|---|
| MW-205 | 1.86 | Eastern Plume | 1 |
| MW-208 | 0.24 | Eastern Plume | 1 |
| MW-213 | 1.22 | Not applicable | 1 |
| MW-214A | 36.85 | 1 and 3 | 2 |
| MW-215 | 0.27 | 1 and 3 | 1 |
| MW-218 | 0.01 | 1 and 3 | 1 |
| MW-229A | 0.91 | Eastern Plume | 1 |
| MW-230A | 0.13 | Eastern Plume | 1 |
| MW-230B | 0.16 | Eastern Plume | 1 |
| MW-231A | 0.77 | Eastern Plume | 1 |
| MW-231B | 0.17 | Eastern Plume | 1 |
| MW-233 | 0.0001 | 1 and 3 | 1 |
| MW-305 | 21.83 | 1 and 3 | 2 |
| MW-312 | 0.88 | 1 and 3 | 2 |
| MW-314B | 0.54 | 1 and 3 | 2 |
| MW-315A | 0.11 | 1 and 3 | 2 |
| MW-315A | 0.11 | Eastern Plume | 3 |
| MW-315B | 8.50 | 1 and 3 | 2 |
| MW-318 | 3.12 | 1 and 3 | 2 |
| MW-319 | 18.99 | 1 and 3 | 2 |
| MW-320 | 15.02 | 1 and 3 | 2 |
| MW-322 | 11.91 | 1 and 3 | 2 |
| MW-401 | 0.28 | Eastern Plume | 1 |
| MW-403 | 1.47 | Not applicable | 1 |
| MW-407 | 0.37 | Eastern Plume | 1 |
| MW-807 | 0.67 | 8 | 1 |
| MW-808 | 0.2 | 8 | 1 |
| OW-812 | 0.005 | 8 | 1 |
| **Geometric Mean** | **0.52** | | |
| **Mean** | **4.52** | | |

NOTE: Hydraulic conductivity measurements were used for monitoring wells identified as being fully screened in the transition unit.

Sources:
1. Table 4-3, Remedial Investigation (E.C. Jordan 1990).
2. Table 3-2, Supplemental Remedial Investigation (E.C. Jordan 1991).
3. Table 8-3, Supplemental Remedial Investigation (E.C. Jordan 1991).

# TABLE 3 ANTICIPATED RANGE OF MODEL INPUT PARAMETERS

| Parameter | Anticipated Calibration Range/Values | Calibration Range Rationale |
|---|---|---|
| Horizontal Hydraulic Conductivity[(a)] | Upper Sand Model Layers: 0.009-49.05 ft/day<br><br>Transition Model Layers: 0.0001-36.85 ft/day<br><br>Lower Sand Model Layers: 0.0009-4.905 ft/day | Maximum and minimum measured hydraulic conductivities noted in Remedial Investigation and Supplemental Remedial Investigation. Lower Sand range assumed to be one order of magnitude less than Upper Sand range based on higher amount of fine sand and silt in Lower Sand unit |
| Ratio of Horizontal to Vertical Hydraulic Conductivity[(b)] | Upper Sand Model Layers: 10:1-20:1<br><br>Transition Model Layers: 10:1-20:1<br><br>Lower Sand Model Layers: 10:1-20:1 | Assumed based on literature values (Fetter 1994) |
| Recharge | 8.2-12.3 in./year | Maximum and minimum estimated recharge rate noted in previous model (ABB-ES 1993, Page 3-9) |
| Stream Conductance | 10-600 $ft^2$/day | Maximum and minimum estimated stream conductance noted in previous model (ABB-ES 1993, Page 5-9) |
| Porosity | 0.2-0.4 | Estimated based on porosity of aquifer materials (Fetter 1994) |
| Specific Yield[(c)] | Upper Sand Model Layers: 0.01-0.46<br><br>Transition Model Layers: 0.01-0.39<br><br>Lower Sand Model Layers: 0.01-0.46 | Approximate range provided for material in *Applied Groundwater Modeling* (Andersen and Woessner 1992) |
| Specific Storage[(d)] | Upper Sand Model Layers: 0.0003 (1/ft)<br>Transition Model Layers: 0.00004 (1/ft)<br>Lower Sand Model Layers: 0.0003 (1/ft) | Approximate range provided for material in *Applied Groundwater Modeling* (Andersen and Woessner 1992) |

(a) Denotes input values that will be the primary focus of model calibration. These values will be altered during calibration to optimize model output results.
(b) The ratio of vertical to horizontal conductivity was estimated based on standard modeling input values and literature sources, including Fetter 1994.
(c) Specific yield is used for unconfined layers. Values taken from *Applied Groundwater Modeling*, Table 3.5 (Andersen and Woessner 1992).
(d) Specific storage is used for confined layers only. Values taken from *Applied Groundwater Modeling*, Table 3.4 (Andersen and Woessner 1992). Upper and Lower Sand Layers assumed to be upper range of loose sand. Transition Layer assumed as lower value of dense sand.

# TABLE 4 WATER LEVEL ELEVATION DATA, 1995-2004

| Well ID | Minimum Water Level Elevation (ft AMSL) | Maximum Water Level Elevation (ft AMSL) | Mean Water Level Elevation (ft AMSL) | Standard Deviation | Number of Data Used in Calculation |
|---|---|---|---|---|---|
| MW-105A | 19.84 | 23.94 | 21.77 | 0.90 | 36 |
| MW-105B | 8.79 | 18.82 | 16.38 | 1.52 | 37 |
| MW-106 | 22.89 | 32.20 | 27.61 | 2.23 | 37 |
| MW-1104 | 26.69 | 52.81 | 47.32 | 4.15 | 36 |
| MW-205 | 20.52 | 24.72 | 22.18 | 0.92 | 37 |
| MW-206A | 21.17 | 27.81 | 23.89 | 1.49 | 37 |
| MW-206B | 21.20 | 26.37 | 23.50 | 1.18 | 36 |
| MW-207A | 20.96 | 24.06 | 23.33 | 1.02 | 26 |
| MW-207B | 13.96 | 20.11 | 17.19 | 1.72 | 37 |
| MW-208 | 23.28 | 32.45 | 27.87 | 2.21 | 37 |
| MW-209 | 24.39 | 32.98 | 28.61 | 2.11 | 37 |
| MW-222 | 25.04 | 36.02 | 29.81 | 2.26 | 37 |
| MW-223 | 19.80 | 32.51 | 27.97 | 2.47 | 37 |
| MW-224 | 25.58 | 34.63 | 30.39 | 2.10 | 37 |
| MW-225A | 22.16 | 30.79 | 26.34 | 2.00 | 37 |
| MW-225B | 15.44 | 29.42 | 24.96 | 2.57 | 37 |
| MW-229A | 18.85 | 21.68 | 20.23 | 0.63 | 36 |
| MW-229B | 13.47 | 16.15 | 14.70 | 0.71 | 37 |
| MW-230A | 18.52 | 22.81 | 20.75 | 0.87 | 37 |
| MW-231A | 16.61 | 25.20 | 24.07 | 1.46 | 37 |
| MW-231B | 19.93 | 22.06 | 21.08 | 0.59 | 37 |
| MW-303 | 30.32 | 33.13 | 31.76 | 0.60 | 37 |
| MW-305 | 28.53 | 36.26 | 32.40 | 2.66 | 37 |
| MW-306 | 30.59 | 36.01 | 33.53 | 1.26 | 37 |
| MW-307 | 45.07 | 47.83 | 46.49 | 0.67 | 35 |
| MW-308 | 30.70 | 34.13 | 32.47 | 0.84 | 37 |
| MW-309A | 22.78 | 28.84 | 24.52 | 2.14 | 29 |
| MW-309B | 18.77 | 22.32 | 20.69 | 0.93 | 28 |
| MW-310 | 22.21 | 29.33 | 25.19 | 1.53 | 37 |
| MW-311 | 0.76 | 21.48 | 12.79 | 7.81 | 35 |
| MW-312 | 21.10 | 25.55 | 24.09 | 0.99 | 26 |
| MW-313 | 11.41 | 14.41 | 12.91 | 0.73 | 37 |
| MW-316A | 29.59 | 44.65 | 32.70 | 2.71 | 27 |
| MW-316B | 38.85 | 45.36 | 42.59 | 2.11 | 27 |
| MW-317A | 53.53 | 58.92 | 56.96 | 1.76 | 27 |
| MW-317B | 53.55 | 58.95 | 56.87 | 1.82 | 27 |
| MW-318 | 8.44 | 19.94 | 18.12 | 1.90 | 37 |
| MW-319 | 21.41 | 31.32 | 26.11 | 2.53 | 37 |
| MW-NASB-212 | 30.29 | 33.66 | 31.83 | 0.76 | 29 |

NOTE: AMSL = Above mean sea level.

| Well ID | Minimum Water Level Elevation (ft AMSL) | Maximum Water Level Elevation (ft AMSL) | Mean Water Level Elevation (ft AMSL) | Standard Deviation | Number of Data Used in Calculation |
|---|---|---|---|---|---|
| P-103 | 31.93 | 37.35 | 34.93 | 1.33 | 35 |
| P-105 | 29.94 | 34.23 | 32.17 | 1.00 | 37 |
| P-106 | 25.64 | 30.90 | 28.29 | 1.25 | 37 |
| P-110 | 32.63 | 34.35 | 33.65 | 0.91 | 3 |
| P-111 | 21.64 | 28.26 | 26.07 | 1.48 | 31 |
| P-112 | 24.77 | 30.29 | 28.61 | 1.51 | 27 |
| P-121 | 34.22 | 45.68 | 37.10 | 3.97 | 27 |
| P-123 | 23.80 | 23.80 | 23.80 | NA | 1 |
| P-124 | 28.10 | 30.26 | 29.22 | 1.13 | 4 |
| P-132 | 14.79 | 26.38 | 24.68 | 1.76 | 37 |
| Overall Statistics (Average) | **22.83** | **29.76** | **26.75** | **1.73** | |

# REFERENCES

ABB Environmental Services, Inc. (ABB ES). 1993. Numerical Modeling Report, Naval Air Station, Brunswick, Maine. January.

Andersen, M. and W. Woessner. 1992. Applied Groundwater Modeling. Academic Press.

EA Science and Technology. 2000. Final 1998 Annual Report, Monitoring Events 11 through 13, Sites 1 and 3 and Eastern Plume, Naval Air Station, Brunswick, Maine. February.

EA. 2003. Conceptual Model of the Eastern Plume. December.

EA. 2004. Summary Report for the Direct-Push Investigation at the Southern Boundary of the Eastern Plume, Naval Air Station, Brunswick, Maine. December.

E.C. Jordan. 1990. Draft Final Remedial Investigation Report, Naval Air Station, Brunswick, Maine. August.

E.C. Jordan. 1991. Draft Final Supplemental Remedial Investigation Report, Naval Air Station, Brunswick, Maine. August.

Fetter, C.W. 1994. Applied Hydrogeology, 3rd Edition. Prentice-Hall, Inc., ISBN 0-02-336490-4.

Greenwald, R., M. Beljin, and R. Ross. 2005. Capture Zone Analyses for Pump-and-Treat Systems. EPA Training Course. 7 June.

Hager Geoscience. 2004. Geophysical Investigations of Bedrock Fracture Zone at Site 11 and Areas Downgradient, Naval Air Station, Brunswick, Maine. January.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald. 2000. MODFLOW-2000, the U.S. Geological Survey Modular Groundwater Model – User Guide to Modularization Concepts and the Groundwater Flow Process. U.S. Geological Survey Open-File Report 00-92, 121 p.

# Appendix A

# Responses to Comments from Site Regulators on the Draft Work Plan

# RESPONSE TO COMMENTS FROM THE MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION ON THE GROUNDWATER MODELING WORK PLAN DATED SEPTEMBER 2005 NAVAL AIR STATION BRUNSWICK, MAINE

| **Commentor: Claudia Sait** | |
|---|---|
| **Comment Issue Date: 29 November 2005** | **Navy Response Date: 2 December 2005** |

The Maine Department of Environmental Protection (MEDEP) has reviewed the draft "Groundwater Modeling Work Plan, dated September 2005, prepared by EA Engineering, Science, and Technology. Based on that review, MEDEP has the following comments and issues.

## GENERAL COMMENTS

1. MEDEP has reviewed the USEPA comments dated November 15, 2005 and agrees with those comments, in particular the issues of horizontal/vertical conductivities, evaluation of concentration trends, and determination of site-specific K's for the lower sand unit.

   ***Response***—Adjustment of vertical anisotropies will be a part of the model calibration and sensitivity analysis. The six-step process for Capture Zone Analysis is to be conducted with modeling as just one part of the effort. Evaluation of concentration trends can be performed outside of the model, or if necessary with the aid of a contaminant transport model such as MT3D-MS or RT3D. The Navy proposes performing slug tests on a number of selected wells that are known to be screened within the lower sand to gain a better understanding of conductivities.

2. The overall plan is logically presented and includes the necessary elements and provisions for revising model inputs and evaluating results as needed. The overall performance goals of the groundwater extraction system when it was designed generally agree with those outlined in the latest 5-year Review (2005), although it is evident the system has not achieved the level of capture anticipated, and pumping rates are below the original modeled values. The revised model will be an important tool in evaluating the next steps in optimization of the groundwater extraction system.

   ***Response***—Comment noted.

   As part of the review process, there should be an intermediate step where the conceptual site model and understanding of the site stratigraphy are revised and summarized. The extensive drilling done at the southern boundary, as well as the direct push, clay surface geophysics and other investigations conducted in the northern portion of the plume have certainly refined the site geology since the previous model was designed. This information must be synthesized and presented to the stakeholders as part of the modeling report.

   ***Response***—As part of the modeling effort, the top and bottom of each model layer will be interpolated from existing stratigraphic data available for the site. Specifically, stratigraphic contact data from selected borings, EC logs, CP logs, etc. will be entered into the model and used to generate an interpolated surface representing the top and bottom of each stratigraphic unit present at the site. This process will generate a finite difference 3-D model that will represent the geology of the site from ground surface to the top-of-clay contact. The MODFLOW model will be based on this 3-D model. The Navy proposes a meeting to present the solid 3-D model to site stakeholders prior to the calibration process, as it is expected that the accurate representation of site geology will play a primary role in the success of the calibration and meeting the Work Plan objectives.

3. For specificity MEDEP suggests that "Sites 1 and 3 and the Eastern Plume" be added to the title.

   ***Response***—Agreed. "Sites 1 and 3 and the Eastern Plume" has been added to the title.

4. Section 5, Objective 1, Page 11:

   - MEDEP staff attended the EPA Capture Zone Analysis training in Boston this month that outlines the six-step process referenced in this section, and supports following this approach to the Eastern Plume.

     ***Response***—Comment noted.

   - The objectives laid out in the Plan, particularly Objective 1, suggest that the modeling will attempt to describe the effectiveness of the extraction well network at capturing the plume. There was some indication on the November conference call that the focus was also to evaluate the impact of the infiltration gallery on the behavior of the Eastern Plume. MEDEP supports the concept of the model doing both of those things, as both the well network and the infiltration gallery have certainly influenced the plume's current configuration.

     ***Response***—While it is not considered the primary objective of this modeling effort, the infiltration gallery will be simulated in this modeling effort as it is located within the model domain. Using the flow model, it will be possible to evaluate the effects of the gallery on the surrounding flow field, and by implication its effects on the behavior of the Eastern Plume. It is estimated that the gallery's effect on the surrounding aquifer is to increase the hydraulic gradient, thus increasing groundwater velocities. Particle tracking using MODPATH would be able to quantify the increase in groundwater velocities as a result of the infiltration gallery. Since the gallery's effects on the plume may be one of dispersion in addition to advection, a solute transport model may give a better indication of the gallery's effects on the behavior of the Eastern Plume if a more in-depth evaluation is required.

5. Section 3.3, Page 6:

   If there are wells screened in the lower sand they could be slug-tested to field-check the literature values for K in that unit. If there is water elevation response data from the initial activation of EW-2A or 5A, wells screened in the lower sand, that data could also be utilized.

***Response***— Prior to the modeling effort, the Navy proposes performing slug tests on a number of selected wells that are known to be screened within the lower sand. This should give a better indication of the range of conductivity values within the lower sand sub-unit. After a review of the site database, wells with more than half of their screens within the lower sand include: EP-07, EP-11, EP-12, EP-14, EP-20, EW-2A, MW-207A, MW-330, MW-331, MW-333, MW-NASB-028, MW-NASB-039, MW-NASB-050.

6. Section 4, Page 8:

If water elevation data is available from the 2001 shutdown of the system, the non-pumping head data can be used to help calibrate the model.

***Response***—Agreed. A data set representing non-pumping conditions would aid in calibrating the model. If such a data set exists, it could be used during model verification.

**RESPONSE TO COMMENTS FROM THE**
**U.S. ENVIRONMENTAL PROTECTION AGENCY**
**ON THE GROUNDWATER MODELING WORK PLAN**
**DATED SEPTEMBER 2005**
**NAVAL AIR STATION BRUNSWICK, MAINE**

| **Commentor: Christine A.P. Williams** | |
|---|---|
| **Comment Issue Date: 15 November 2005** | **Navy Response Date: 2 December 2005** |

Pursuant to ' 6 of the Naval Air Station Brunswick, Maine Federal Facility Agreement dated October 19, 1990, as amended (FFA), the Environmental Protection Agency has reviewed the subject document and comments are below.

## GENERAL COMMENTS

1. The proposed numerical model development is generally well conceived. The model should serve as a useful tool in assessing the performance of the Eastern Plume extraction system. In particular, the model should give an indication of the extent of capture of the known contaminant mass distribution, as well as the extent of hydraulic control on the hydrological system as a whole. It may also prove to have utility in optimizing the extraction system (e.g., adjusting the pumping rates at the individual extraction wells to achieve some prescribed balance of hydraulic control and mass extraction).

   ***Response***—Comment noted.

2. However, this model will not satisfy the finding of the BNAS Second Five Year Review that the groundwater IC boundaries need to be revised. It was discussed with EPA and DEP that the revision would be based on modeling. Please provide a schedule for each site for revising the IC boundaries as the 5-yr review did not.

   ***Response***—In the event that a production well at a known location and projected pumping rate is planned for the base, the Navy will consider developing a groundwater model specific to those parameters to determine what, if any, effects such a well would have on the existing groundwater plume and treatment system. The decision to develop this groundwater model will be made after discussions with the stakeholders.

3. While the proposed MODFLOW model, along with the particle tracking code MODPATH, should provide valuable insight into the hydraulics of the system, it is necessarily limited in its predictive capabilities for contaminant transport. In particular, it is noted that the list of goals for assessing Acapture effectiveness@ given on p. 11, sec. 5, includes, AStep 5 - Evaluate concentration trends.@ It is not clear how this goal will be met with a flow model only. Nonetheless, the Groundwater Modeling System (GMS) package does include transport codes (e.g., MT3DMS and RT3D), and provides the necessary interface with MODFLOW. If, in the future, there is interest in expanding the modeling effort to include contaminant transport simulations (e.g., to optimize the extraction system giving some weight to mass extraction rate), the proposed flow modeling will support such an effort.

***Response***—The Navy recognizes that the MODFLOW model and subsequent particle tracking using MODPATH is limited in its predictive capabilities for contaminant transport. However, MODPATH does simulate advective transport and will, therefore, provide a conservative estimate of contaminant transport mechanisms. In regards to assessing capture effectiveness, it is recognized that the flow model will be only one part in analyzing the capture effectiveness of the current extraction system network. If required, the flow model will provide a basis for any future transport model development.

## SPECIFIC COMMENTS

4. **p. 3, sec. 2.1:** The Work Plan is not entirely consistent in the nomenclature used to describe the hydrostratigraphy and the way in which it is proposed to represent it in the model. In particular, the first bullet on this page indicates that the Atransition unit@ refers to the entire sequence between the upper sand and the Presumpscot clay, and that an interval *within* this sequence is referred to as the Alower sand.@ The latter is described as A[a] mappable sandy interval ... near the base of the transition unit in some portions of the Eastern Plume.@ In sections 3.2 and 3.3, it seems that the transition unit and the lower sand are treated as separate stratigraphic intervals. It is understood that it is critical to break out the lower sand as a separate unit for the modeling in order to capture the observation that the majority of the contamination is found in this subdomain. For clarity, perhaps some additional nomenclature is needed. For example, the Atransition@ discussed in section 3.2, and planned to be represented by two finite-difference layers might be referred to as the Aupper transition,@ or some similar, unique description. The Alower sand@ might be referred to as the Alower sand subunit@ of the transition, or similarly. In any case, it should be made clear in sections 3.2 and 3.3 that the Atransition@ unit, as used historically, is to be represented by four model layers, two of which are intended to represent the Alower sand@ portion of the transition.

   ***Response***—For clarity, Section 3.3 has been renamed as Sub-Section "3.2.1 Lower Sand Sub-Unit." As suggested, the lower sand has been referred to in the text as the lower sand sub-unit of the transition unit. The last paragraph of Section 3.2 has been revised to read:

   > *The transition will be modeled as four layers to account for changes in unit thickness over the model domain. Two of those layers will represent the lower sand sub-unit.*

5. **p. 6, sec. 3.2:** The description of the Atransition unit@ in this section refers more specifically to the upper portion of the transition, which is described as interbedded sand, silt, and clay. The range of K values given includes some fairly high results (up to 36.85 ft/day). Has an effort been made to identify slug tests that were performed in wells screened above the lower sand from those in wells screened predominantly in the lower sand? Given that the working conceptual model for the hydraulic controls in the system seems to regard the upper portion of the transition unit as a rather tight unit overall (at least vertically C i.e., it serves as a confining unit to the lower sand), it would be worthwhile to attempt to identify slug tests that are representative of the section intended to be represented by the two proposed Atransition unit@ layers. If the higher K values (e.g., >10 ft/day) included in the tabulation of results for the transition layer (i.e., Table 2) are actually from the lower sand, they should not condition the range of K anticipated for the transition unit as the term is used here (see Table 3).

*Response*—After a review of the boring logs of those wells listed in Table 2 with higher K values (e.g., >10 ft/d), the following wells appear to be screened in sandier intervals of the transition unit: MW-214A, MW-319, and MW-320. It is anticipated that conductivities from these wells will be applied to the lower sand model layers and not to transition model layers. Given the lack of conductivity data for the lower sand, the Navy proposes slug testing selected wells that are known to be screened across the lower sand.

6. **p. 6, sec. 3.3:** The text states that there are no slug test data available for the lower sand. Is it true that none of the wells listed in Table 3 penetrate the lower sand? If not, it may be worthwhile to slug test several key wells that are known to be screened across the lower sand (e.g., MW-331, MW-311, etc.) in order to constrain the conductivity of this layer. The Conceptual Model for the plume (December 2004) states, AThe majority of groundwater flow in the transition unit occurs within the lower sand interval.@ It seems out of balance with this inference to suppose that the conductivity of the lower sand is lower (0.028 to 2.835 ft/d, based on typical silty to fine sand values) than the range given for the confining units above (up to 36.85 ft/d).

   *Response*—The Navy agrees that applying measured conductivities from the transition unit to the model layers representing the lower sand sub-unit is questionable. However, none of the wells listed in Table 3 (i.e., those wells that were slug tested as part of the remedial investigation and supplemental remedial investigation) are screened within the lower sand unit. Prior to the modeling effort, the Navy proposes performing slug tests on a number of selected wells that are known to be screened within the lower sand. This should give a better indication of the range of conductivity values within the lower sand sub-unit. After a review of the site database, wells with more than half of their screens within the lower sand include: EP-07, EP-11, EP-12, EP-14, EP-20, EW-2A, MW-207A, MW-330, MW-331, MW-333, MW-NASB-028, MW-NASB-039, and MW-NASB-050. It is noted that the geometric mean of measured conductivity values for the transition unit is 0.52 ft/d and that a value of 36.85 ft/d will probably be considered an outlier and not factored into any conductivity zonation. It is anticipated that the final calibrated conductivity value(s) for the transition unit will be within an order of magnitude of the geometric mean.

7. **p. 6, sec. 3.3:** The Work Plan proposes to model the lower sand by two layers in order to accommodate the variation in thickness over the model domain. It is noted that there has been much discussion at recent technical meetings among Navy, its contractors, and regulators concerning the possible role of the Aclay bowls@ in controlling the distribution of CVOCs. The MEDEP advanced a working hypothesis that the CVOCs have tended to concentrate in the lower sand where it fills depressions (Abowls@) in the Presumpscot clay surface. At the technical meeting of October 4, 2005, concern was raised concerning the ability of an extraction screen placed in the Abowl@ near EP-LOG-03 to capture contamination that lies in the Abowl@ upgradient to the north, near EP-LOG-01, because of the intervening Aridge@ in the clay surface. The model offers an opportunity to explore these questions, i.e., why the CVOCs might be localized in the bowls, and how well adjacent bowls are connected hydraulically. However, these questions may require greater vertical discretization (i.e., more layers) within the lower sand, as the issues are closely tied to differences in groundwater flow at different elevations relative to the clay surface, and resolution of vertical gradients.

*Response*—The Navy suggests that the flow model and subsequent particle tracking could serve as a way to confirm (as one line of evidence) MEDEP's working hypothesis. However, it is noted that particle tracking simulates advective transport only and that a contaminant transport model such as MT3D-MS or RT3D based on the flow model would further aid in determining whether MEDEP's hypothesis is accurate. It is noted that the modeling effort will be an iterative process and, as a starting point, the lower sand sub-unit will be modeled using two layers, but may be modeled using additional model layers if greater vertical discretization is deemed necessary once the modeling effort is underway. It is anticipated that the flow model will act as a "working document," and that future needs can be addressed by the model. The Navy suggests that as part of the formal sensitivity analyses, the model layers representing the lower sand could be further divided vertically.

8. **p. 7, sec. 3.4:** The Work Plan proposes to make the top-of-clay surface the base of the model, i.e., represent this as an impermeable boundary. This assumption appears to be well motivated for the principal purposes of the modeling study, as the conductivity of the clay is undoubtedly extremely low. However, the model will be unable to address one phenomenon that has been noted at Sites 1 and 3. Wells interior to the slurry wall have recorded rising sodium concentrations, and it has been suggested that this is due to upward seepage of relict seawater from the Presumpscot clay. There is a large head difference from the upgradient side of the slurry wall to the inside of the wall, which will drive some leakage upward into the enclosed area. In the larger hydrological system, this is likely to be a very small perturbation to the water balance, and its neglect will not affect simulations of the (predominantly horizontal) flow around the slurry wall.

   *Response*—Agreed. Since the objective of the flow model is to assess the effects of the cap and slurry wall, using the top-of-clay surface as the base of the model is presumed to be a valid approach.

9. **p. 7, sec. 3.4:** The section on boundary conditions does not discuss the anticipated approach to specifying recharge across the model domain. A range of reasonable values is given in Table 3. Is the intent to specify uniform recharge, and vary its value across the entire domain in calibration and sensitivity runs? Will an attempt be made to recognize the effect of the very large paved area (runways, taxiways, aprons, etc.) in the northwestern portion of the model domain?

   *Response*—It is anticipated that, during the initial calibration runs, a spatially uniform recharge rate will be applied across the model domain. However, subsequent zonation may follow depending upon the results of the initial calibration runs. Specifying zones of recharge will be an iterative process during calibration. Recharge zonation will be justified on the basis of a successful calibration. Paved areas within the model domain will be addressed when specifying different zones of recharge. It is understood that runoff from paved areas enters the storm sewer system which discharges at several points into tributaries of Mere Brook east of the tarmac. An effort will be made to simulate this.

10. **p. 8, sec. 4:** The third bullet on this page states that a transient calibration will be carried out. Are the necessary data available to support this calibration? Have data loggers been deployed in multiple monitoring wells surrounding one or more extraction wells in order to capture the transient response following a change in pumping rate (i.e., on a time scale of

minutes to hours)? If the available water-level data are typically from quarterly monitoring events, they will likely be unable to resolve the transient response due to changes in the extraction configuration. Rather, modeling of the different extraction configurations may be more like a series of steady states. The motivation for running a transient simulation with very large time steps is not clear. It may be more efficient, as well as closer to the physical reality, simply to run a steady-state simulation for each new extraction configuration. This will still provide a powerful test of the model and an opportunity to refine the calibration, but will not introduce the additional parameters (e.g., storativities) that enter a transient calculation, but may be quite unconstrained by the available data.

***Response***—While a transient flow model will not be able to simulate temporal changes of minutes or hours, it will be able to simulate temporal changes on the order of weeks and months. It is possible that the effects of extraction rate changes will have effects on the order of weeks and months so there may be some utility in attempting to model longer time scale changes. A transient model may also aid in assessing aquifer response to seasonal variations in recharge, and stream discharge. Transient release of water may or may not be an important consideration in assessing the aquifer's response to different pumping regimes. To quantify this, a transient analysis will be necessary. Despite the lack of any site-specific storativity data, an estimate using literature values may provide insight into the hydraulics of the aquifer system. It is also noted that any future transport model (MT3D-MS or RT3D) will necessarily be based on a calibrated transient flow model.

11. **p. 10, sec. 4.1:** The value of the Avalidation@ step, as described, is unclear. If the most recent gauging data are collected under the same general conditions (extraction configuration, in particular) as the previous data that is used in calibration, it is not clear how this exercises the model. If the water levels differ significantly from previous rounds collected under a similar pumping scenario, the differences may be a consequence of some genuine natural variability, such as annual-scale variation in rain/snowfall. A more meaningful validation exercise would be to calibrate the model using data collected under one or more extraction scenarios, and then simulate an entirely new pumping configuration without adjusting any other input parameters. Please clarify the intent here. (A minor semantic point: Many would call the process described a Averification@ exercise; i.e., a comparison of modeled response to the Aground truth@ of field data, with the model defined and calibrated on independent configurations. The same practitioners would reserve Avalidation@ for the process of confirming that the model is based on sound physics and accurate and stable numerical algorithms.)

    ***Response***—The EPA is correct in its semantic point. "Validation" in the text has been replaced by "verification." To test the model, it would seem useful to use a different historical data set under different hydraulic stresses: seasonal changes in recharge, pumping stresses, stream discharge, but keep temporally unaffected parameters the same, such as hydraulic conductivity. Adjusting temporally affected parameters while keeping temporally unaffected ones the same should also serve as one check against non-uniqueness.

12. **p. 11, sec. 5, first bullet:** Step 5 enumerated here is to Aevaluate concentration trends.@ It is not clear how this can be done using only a flow model and particle tracking. This may require development of a transport model. Please clarify how it is anticipated to meet this goal.

*Response*—It is recognized that the flow model will serve as only one line of evidence in analyzing the capture effectiveness of the current extraction system network. The development of a transport model may be required in the future.

13. **p. 11, sec. 5, second bullet:** The text states that the modeled flow field will be used to Aestimate how long impacted groundwater may impact the surrounding areas of Sites 1 and 3. Again, in the absence of transport model, how will this objective be met? Please expand.

    *Response*—Using the transient flow model, the construction of the slurry wall and cap and subsequent partial de-watering of the aquifer within the slurry wall can be simulated. Subsequent particle tracking using MODPATH will provide a conservative estimate of contaminant transport travel times as it simulates advective transport only. It is acknowledged that, depending on flow model and particle tracking results, the development of a transport model may be warranted.

14. **Table 2:** The NOTE at the bottom of the table may have been carried inadvertently from the previous table. It is noted clearly that these wells, screened in the transition unit, were fully screened in sand. Please check.

    *Response*—Correct, the note was carried over from Table 1. The table has been revised accordingly.

15. **Table 3:** The anticipated parameters for the modeling include the common assumption of vertical conductivities 1/10 of the horizontal conductivities. The modelers might consider including variation of the anisotropy in the model calibration, particularly for the intermediate transition unit. This unit is described as interbedded sands, silts, and clays, which apparently acts as a confining layer for the lower sand. The sandy intervals, if interconnected, can give rise to fairly large effective horizontal conductivities, while the fine-grained interbeds can result in very low effective vertical conductivities. Under these conditions, it is plausible that the conductivity ration may be greater than 10:1.

    *Response*—The Navy agrees that given the interbedded nature of the transition unit, vertical anisotropies greater than 1/10 may be possible. This parameter will be adjusted during calibration, and will be included in the formal sensitivity analyses.

16. **Table 3:** The table includes anticipated values for the specific yield of the transition and lower sand units. Is it known from field observations, or anticipated in any of the modeling runs, that the water table will be present anywhere in these units.

    *Response*—It is estimated that the water table is present within the upper sand and transition units while the lower sand sub-unit is probably fully saturated and semi-confined. Therefore, when conducting any transient flow simulations, specific storage values will be applied to the lower sand instead of specific yield.

**FOLLOWUP RESPONSE TO COMMENTS FROM THE U.S. ENVIRONMENTAL PROTECTION AGENCY ON THE GROUNDWATER MODELING WORK PLAN DATED SEPTEMBER 2005 NAVAL AIR STATION BRUNSWICK, MAINE**

| Commentor: Christine A.P. Williams | |
|---|---|
| Comment Issue Date: 19 December 2005 | Navy Response Date: 23 January 2006 |

Pursuant to ' 6 of the Naval Air Station Brunswick, Maine Federal Facility Agreement dated October 19, 1990, as amended (FFA), the Environmental Protection Agency has reviewed the subject document and comments are below.

## GENERAL COMMENTS

3. While the proposed MODFLOW model, along with the particle tracking code MODPATH, should provide valuable insight into the hydraulics of the system, it is necessarily limited in its predictive capabilities for contaminant transport. In particular, it is noted that the list of goals for assessing Acapture effectiveness@ given on p. 11, sec. 5, includes, AStep 5 - Evaluate concentration trends.@ It is not clear how this goal will be met with a flow model only. Nonetheless, the Groundwater Modeling System (GMS) package does include transport codes (e.g., MT3DMS and RT3D), and provides the necessary interface with MODFLOW. If, in the future, there is interest in expanding the modeling effort to include contaminant transport simulations (e.g., to optimize the extraction system giving some weight to mass extraction rate), the proposed flow modeling will support such an effort.

   ***Response***—The Navy recognizes that the MODFLOW model and subsequent particle tracking using MODPATH is limited in its predictive capabilities for contaminant transport. However, MODPATH does simulate advective transport and will, therefore, provide a conservative estimate of contaminant transport mechanisms. In regards to assessing capture effectiveness, it is recognized that the flow model will be only one part in analyzing the capture effectiveness of the current extraction system network. If required, the flow model will provide a basis for any future transport model development.

   ***Followup Comment***—The Response is appropriate. The intent of the original Comment was simply to note that the hydraulics modeling alone may not be capable of addressing all of the goals detailed in the Work Plan. This is particularly so with respect to any attempt to test the model in detail against historical trends in concentrations at specific monitoring points, or to use the model to project trends forward under revised extraction scenarios. As acknowledged by the Navy in the Response, a contaminant transport model may be indicated at some point, and the investment in the MODFLOW model can be carried forward.

   The response asserts that particle tracking (i.e., advective transport only) is "conservative." It is agreed that certain estimates based on advective transport only can be regarded as conservative, but it is cautioned that this depends upon the question being asked. For example, if one were interested in a "conservative," or "worst-case," concentration expected at a point downgradient of a known "hotspot," an advection model can provide an estimate (i.e., it is the highest concentration currently located along the particle pathline through the point of interest). However, if one were interested in the potential impacts at a location downgradient and slightly cross-gradient to the current plume footprint, the particle tracking would not be "conservative," because dispersion may bring contamination to such a point, while advection alone may not.

***Followup Response***—Comment noted. As stated previously, a flow model is necessarily limited in its predictive capabilities for contaminant transport. It is acknowledged that the development of a contaminant transport model may be required at a later date.

## SPECIFIC COMMENTS

6. **p. 6, sec. 3.3:** The text states that there are no slug test data available for the lower sand. Is it true that none of the wells listed in Table 3 penetrate the lower sand? If not, it may be worthwhile to slug test several key wells that are known to be screened across the lower sand (e.g., MW-331, MW-311, etc.) in order to constrain the conductivity of this layer. The Conceptual Model for the plume (December 2004) states, AThe majority of groundwater flow in the transition unit occurs within the lower sand interval.@ It seems out of balance with this inference to suppose that the conductivity of the lower sand is lower (0.028 to 2.835 ft/d, based on typical silty to fine sand values) than the range given for the confining units above (up to 36.85 ft/d).

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   ***Followup Comment***—The proposal to slug test wells set in the lower sand is welcome, and should provide better constraints on the K to be assigned to that subunit. It is agreed that the geometric mean found previously for the transition unit appears to be reasonable, and that model calibration may result in an adjustment to this parameter in any case.

   ***Followup Response***—Comment noted.

7. **p. 6, sec. 3.3:** The Work Plan proposes to model the lower sand by two layers in order to accommodate the variation in thickness over the model domain. It is noted that there has been much discussion at recent technical meetings among Navy, its contractors, and

regulators concerning the possible role of the Aclay bowls@ in controlling the distribution of CVOCs. The MEDEP advanced a working hypothesis that the CVOCs have tended to concentrate in the lower sand where it fills depressions (Abowls@) in the Presumpscot clay surface. At the technical meeting of October 4, 2005, concern was raised concerning the ability of an extraction screen placed in the Abowl@ near EP-LOG-03 to capture contamination that lies in the Abowl@ upgradient to the north, near EP-LOG-01, because of the intervening Aridge@ in the clay surface. The model offers an opportunity to explore these questions, i.e., why the CVOCs might be localized in the bowls, and how well adjacent bowls are connected hydraulically. However, these questions may require greater vertical discretization (i.e., more layers) within the lower sand, as the issues are closely tied to differences in groundwater flow at different elevations relative to the clay surface, and resolution of vertical gradients.

***Response***—The Navy suggests that the flow model and subsequent particle tracking could serve as a way to confirm (as one line of evidence) MEDEP's working hypothesis. However, it is noted that particle tracking simulates advective transport only and that a contaminant transport model such as MT3D-MS or RT3D based on the flow model would further aid in determining whether MEDEP's hypothesis is accurate. It is noted that the modeling effort will be an iterative process and, as a starting point, the lower sand sub-unit will be modeled using two layers, but may be modeled using additional model layers if greater vertical discretization is deemed necessary once the modeling effort is underway. It is anticipated that the flow model will act as a "working document," and that future needs can be addressed by the model. The Navy suggests that as part of the formal sensitivity analyses, the model layers representing the lower sand could be further divided vertically.

***Followup Comment***—The Response is appropriate. It will be interesting to see if the model as proposed (i.e., two FD layers in the lower sand) provides some insight into the role of the "bowls" in localizing contaminant mass. It is agreed that the need for greater vertical discretization in the lower sand can be assessed after initial results are available.

***Followup Response***—Comment noted.

8. **p. 7, sec. 3.4:** The Work Plan proposes to make the top-of-clay surface the base of the model, i.e., represent this as an impermeable boundary. This assumption appears to be well motivated for the principal purposes of the modeling study, as the conductivity of the clay is undoubtedly extremely low. However, the model will be unable to address one phenomenon that has been noted at Sites 1 and 3. Wells interior to the slurry wall have recorded rising sodium concentrations, and it has been suggested that this is due to upward seepage of relict seawater from the Presumpscot clay. There is a large head difference from the upgradient side of the slurry wall to the inside of the wall, which will drive some leakage upward into the enclosed area. In the larger hydrological system, this is likely to be a very small perturbation to the water balance, and its neglect will not affect simulations of the (predominantly horizontal) flow around the slurry wall.

***Response***—Agreed. Since the objective of the flow model is to assess the effects of the cap and slurry wall, using the top-of-clay surface as the base of the model is presumed to be a valid approach.

***Followup Comment***—Agreed. It is recognized that an assessment of leakage from the clay upward into the slurry-wall containment is not a goal of the current modeling effort.

***Followup Response***—Comment noted.

10. **p. 8, sec. 4:** The third bullet on this page states that a transient calibration will be carried out. Are the necessary data available to support this calibration? Have data loggers been deployed in multiple monitoring wells surrounding one or more extraction wells in order to capture the transient response following a change in pumping rate (i.e., on a time scale of minutes to hours)? If the available water-level data are typically from quarterly monitoring events, they will likely be unable to resolve the transient response due to changes in the extraction configuration. Rather, modeling of the different extraction configurations may be more like a series of steady states. The motivation for running a transient simulation with very large time steps is not clear. It may be more efficient, as well as closer to the physical reality, simply to run a steady-state simulation for each new extraction configuration. This will still provide a powerful test of the model and an opportunity to refine the calibration, but will not introduce the additional parameters (e.g., storativities) that enter a transient calculation, but may be quite unconstrained by the available data.

    ***Response***—While a transient flow model will not be able to simulate temporal changes of minutes or hours, it will be able to simulate temporal changes on the order of weeks and months. It is possible that the effects of extraction rate changes will have effects on the order of weeks and months so there may be some utility in attempting to model longer time scale changes. A transient model may also aid in assessing aquifer response to seasonal variations in recharge, and stream discharge. Transient release of water may or may not be an important consideration in assessing the aquifer's response to different pumping regimes. To quantify this, a transient analysis will be necessary. Despite the lack of any site-specific storativity data, an estimate using literature values may provide insight into the hydraulics of the aquifer system. It is also noted that any future transport model (MT3D-MS or RT3D) will necessarily be based on a calibrated transient flow model.

    ***Followup Comment***—It is agreed that a transient flow model will at least allow an assessment of the time scales characteristic of the response of this system (e.g., to changes in the extraction configuration, seasonal changes in recharge, etc.). However, before investing in the effort to develop a transient flow model, it may be worthwhile to make some preliminary estimates of the relevant time scales. For example, hydraulic adjustment is a diffusive process, the time scale for which scales like $L^2/D$, where L is a length scale, and D is the hydraulic diffusivity. For $K \sim 10$ ft/d and $S = 0.0003$ 1/ft, $D = 33000$ ft$^2$/d. At a distance of 100 ft (e.g., from a well where Q is suddenly changed), the characteristic time for the response to stabilize is of the order of 0.3 d. At 1000 ft (where drawdown maps for the Eastern Plume suggest changes are likely to be imperceptible), the time scale is of the order of 30 d. These time scales are short relative to any available calibration data. (Note, however, that there may be opportunities to collect the appropriate data to calibrate a transient flow model in conjunction with pump testing of a proposed new extraction well near the P-106 "hotspot.")

In addition, it is not clear that a transient flow model is necessary as part of possible future transport modeling. The *transport* model will necessarily be a transient calculation, but there may be no reason not to perform this calculation using a steady flow field. The transport calculations will be vastly simpler and faster assuming a steady-state flow field. It may be relevant to advance the transport simulation through a succession of different steady states (e.g., due to changes in the configuration of the extraction system), but that would not require transient flow simulations.

***Followup Response***—A transport simulation using MT3D-MS is by necessity based on a transient MODFLOW simulation. Should development of a transport model be necessary in the future, a transient flow model will be developed at that time.

13. **p. 11, sec. 5, second bullet:** The text states that the modeled flow field will be used to Aestimate how long impacted groundwater may impact the surrounding areas of Sites 1 and 3. Again, in the absence of transport model, how will this objective be met? Please expand.

***Response***—Using the transient flow model, the construction of the slurry wall and cap and subsequent partial de-watering of the aquifer within the slurry wall can be simulated. Subsequent particle tracking using MODPATH will provide a conservative estimate of contaminant transport travel times as it simulates advective transport only. It is acknowledged that, depending on flow model and particle tracking results, the development of a transport model may be warranted.

***Followup Comment***—It is not clear that a transient flow model is necessary for this assessment. Again, if the hydraulic adjustment to construction of the slurry wall is fast relative to the evolution of the contaminant concentration field, particle tracking based on a steady-state simulation with the slurry wall present may yield the same information. Also, it is noted again that the advective travel-time estimate is "conservative" only in the context of the question(s) being asked. For example, the "first arrival" of contaminant at a downgradient point can be sooner than the advective travel time due to dispersion, and will not be captured by the advection-only model.

***Followup Response***—Based upon the results of the steady-state flow model, a transient flow model may be required at a future date.